REMARKS SUMMARY FOR THE HST-JWST TRANSITION PANEL

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Introduction

Extension of HST operations past its presently assumed termination date requires a compelling scientific program that utilizes the unique aspects of the telescope. Arguably among the most productive and unique accomplishments of HST are its deep fields, the Northern and Southern Hubble Deep Fields and the upcoming Ultra Deep Field with ACS and NICMOS. Although these fields are the deepest probes in space and time of galaxies and AGNs ever produced, they are still limited by the small coverage area. These fields do not integrate over large scale structure and can not measure the evolution of that structure with time. This summary suggests that HST be refurbished with an additional maintenance mission, SM5, and that after SM5 it be dedicated to the production of large scale (1 square degree) deep fields with immediate release of the data and no proprietary restrictions. This produces an extraordinarily valuable data set that is unique to and appropriate for HST. It is certain that JWST will produce a deeper field but its many scientific programs will restrict the field to a relatively small area as has been true for HST to date. This program can be accomplished at 3 levels with increasing scientific productivity at successive levels.

Level 1: Utilization of Existing Instruments

With no new instrument development the deep fields can be produced with the existing Advanced Camera for Surveys, ACS and the Wide Field 3 infrared channel scheduled for installation on SM4. After SM5 these instruments would be dedicated to the production of contiguous deep fields. The observing strategy is similar to the strategies for current deep fields except that the mosaic of images will be designed to produce overlapping coverage of the optical and infrared images. The instruments would be operated in parallel and the motions would insure that all parallel fields will be eventually viewed by both instruments. This mode reduces HST operations complexity as only two instruments are supported and the single program is one of long integrations in one place. Orientation constraints will probably dictate the establishment of at least two separated field areas to insure uninterrupted observations throughout the year. A refurbished HST will be able to operate at low cost for at least 4 years in this mode.

Although the simplest level with no new instrument development, level 1 is not very efficient. There is also the consideration of long term degradation of the ACS detectors due to radiation damage. At the time of SM5 it may have a significant fraction of inoperable or degraded pixels.

Level 2: A Dedicated New Axial Survey Instrument

Production of wide deep fields is much more efficient with a combined optical and infrared instrument designed for efficient deep surveys. The instrument, called Cosmic Surveyor or CS for convenience, operates between 0.25 and 1.8 µm. The longest wavelength is set by thermal emission from the warm HST optics. The field of view of CS is approximately 4x4 arc minutes, larger than any existing or planned HST instrument. The major gain in efficiency, however, is achieved through wavelength multiplexing with dichroics. The optical and IR regions are split by a dichroic and each of these regions again split by another dichroic. The three dichroics produce 4 images of the same field that are recorded by 2 optical and 2 IR 2048x2048 detectors with 0.12" pixels on the sky. The combination of 4 simultaneous bands and larger field alone make CS almost 6 times more efficient than ACS. CS also avoids the technical problems of the wide field imager considered by the HST post SM4 Scientific Review Panel through multiplexing in wavelength space rather than trying to pave a focal plane with detectors. As an axial instrument there are also no issues of displaced Fine Guidance Sensors. A schematic of the dichroic separation and the field of view in the focal plane are shown in Figures 1 and 2.

Dichroics have crossover points in the change from transmission to reflection that produce regions of diminished efficiency. The crossover region is relatively small for present day multilayer dichroics but must be present, nevertheless. To increase the accuracy of photometric redshifts and to eliminate lost spectral regions a second set of dichroics and filters produces 4 more photometric bands centered on the crossover points of the first set. These are mounted in wheels in the typical manner. The output of the instrument is photometric measurements in 8 bands between 0.25 and 1.8 µm. These provide input for standard photometric redshift methods.

Although it may be possible to use the NICMOS Cooling System, NCS, to cool the infrared detectors, this will probably not be necessary. CS, with shorter wavelength cutoff detectors than NICMOS, requires cooling only to 130-140 K. This is currently being achieved with thermoelectric coolers on the IR channel of WF3. The current NICMOS bay may be the appropriate position for CS since it has easy access to the NICMOS external radiator. Appendix A lists the primary properties of the instrument.

The Scientific Program

An essential aspect of the scientific program is that it is a dedicated program exclusively occupying the telescope for two or more years and is considered to be the final HST scientific program. All available orbits are dedicated to observing wide deep fields for cosmological and other investigations. All data are immediately released to the public with no proprietary period. No other instruments are operated, greatly reducing the complexity of operation. This is the only way that the large area fields considered here can be produced. It is introduced as an alternative to the option of turning the telescope off. Note that HST can still respond to extremely important targets of opportunity since it still contains a full complement of operational optical and infrared instruments. Significant operation of other instruments compromises the cost savings obtained by greatly simplified HST operation and reduces the area of the deep fields as well.

The area of each field is one square degree, which in a $H_o = 75$, $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$ cosmology translates to 27 Megaparsecs on a side at a redshift of 1. Two years of operation produces two 1 square degree fields at approximately opposite positions on the sky. The two positions provide targets that satisfy HST pointing and attitude constraints for a whole year. The angular pixel size is 0.12 arc seconds, drizzled to 0.06" in the final image. Each 0.12 arc second pixel has a 1σ depth >31 AB mag in the near infrared and >32 AB mag in the optical (see Table 1.). All observations are natural (zodiacal) background limited.

The total 1 degree field of the target is observed every 28 days, providing the additional benefit of sensitive supernova detection in the field. It is not the intention to follow up the supernova with CS but to provide detections to other groups for follow up. There will be continuous monitoring on a 28 day basis, or 14 day in the level 3 response, as the program is carried out.

CS will integrate for the entire visibility period of an orbit, a period slightly greater than 3000 seconds. The non-destructive readouts of the multiplexers for the optical and infrared arrays provide efficient rejection of cosmic ray events. The CR rejection technique is now automatic in NICMOS data analysis and can easily be implemented with on-board software as is planned for JWST. The average transmitted data rate is then only 4 images every 90 minutes which is easily handled by current HST hardware.

Program Advantages

A significant advantage of the wide deep field is the removal of large scale structure as the dominant error in applying the results of the field to the universe as a whole. Present Hubble Deep Fields are limited by this error in studies of star formation, redshift distribution, distribution of galaxy properties, luminosity evolution and countless other scientific areas that utilize the HDFs.

Another significant advantage is a measurement of the evolution of structure back to a redshift of at least 6. Models of the evolution of the structure of matter are directly checked with these observations. Even a measurement of the evolution of the 2 point correlation function with redshift puts strong constraints on structure formation models.

The large field also provides sufficient area to determine the evolutionary properties of rarer objects such as AGNs, ULIRGs, and possibly sub-mm sources. Although the present HDFs easily reach the depth required to detect these objects, generally only one or two objects are present due to the small size of the field. The almost 700 times larger area of each of the one square degree fields produces enough objects for statistically significant analysis of their evolution. This is particularly important in the search for the low mass but high luminosity objects that may have reionized the universe.

There are many other programs where a set of very deep optical and infrared images of one degree of sky will be of extraordinary usefulness. In the space of this summary it is impossible to list them all, but, it is appropriate to say that the detection of a large number high redshift galaxies of various types for detailed follow up with JWST may be one of the most important benefits of the program.

Level 3: A Duplicate Instrument for an Another Axial Bay

As shown in figure 2 the 4x4 arc minute field effectively fills the field of view available to a single axial HST instrument. The efficiency of operation and the simplicity of the instrument can be improved by duplicating the proposed instrument for insertion in another axial bay. The second instrument would allow both instruments to have fixed filters and dichroics by allocating 4 of the 8 wavelength bands to each instrument. The efficiency will be doubled and the reliability greatly improved. Since the majority of cost of any instrument is in the design, the second instrument should not approach doubling the cost of a single instrument with a more complex design. The detectors will then be even further optimized for the single band that they observe and the redundancy greatly increased.

Complementarity with SNAP

CS is optimized as a wide deep field imager that produces supernova candidates as a very useful by product. SNAP is optimized as a supernova searcher that produces wide deep fields as a very useful by product. As such they complement each other and taken together produce extremely useful data for the astronomical community. Since both instruments are still in the design, or in this case conceptual phase, direct comparisons are difficult and may do disservice to both instruments. It is, however, useful to make a comparison based on the concept of similar detectors for both instruments. In fact the proposed near infrared detectors for both instruments are identical.

CS utilizes the larger 2.4 m mirror of HST as opposed to the proposed 1.8-2.0 m primary for SNAP. CS also has the luxury of long integration times, >3000 seconds whereas SNAP must take short 300 second integrations to cover its field in the appropriate time for supernova searches. The 300 second integrations generally do not put the observation onto the pure square root, background limited, region of the signal to noise ratio versus time curve. This produces poorer signal to noise for equal integration times. This effect alone results in a lower 1σ limiting flux for HST by a factor of 2 in the IR and 1.3 in the optical. (See figure 3). Coupled with the difference in mirror area the intrinsic flux sensitivity of CS is a factor of 3.6 better in the IR and 2.3 in the optical for equal integration times. SNAP does not utilize dichroics for wavelength multiplexing but compensates with the shear number of detectors (36 optical, 36 IR). SNAP has 18 times the detectors as CS (9 times for the level 3 response) and covers 15 times the area as CS. The net available observing time per pixel per filter is then 1.2 times longer for SNAP. The net advantages for CS in limiting flux are then 3.3 in the IR and 2.1 in the optical based on equal efficiencies. SNAP will probably have a better percentage of orbit use than CS but must interrupt the imaging to follow supernovae. Compromises based on the different primary goals of the two projects may drive these numbers further apart.

Based on previous experience and the presence of HST as an existing telescope, the chances of implementing the deep wide field program with a new HST instrument for SM5 are very high. At present it appears that such an implementation could very well precede the implementation of SNAP. The supernova by products of the HST instrument would then provide a very useful input to SNAP planning and implementation.

Conclusion

The scientific program discussed here is an example of a unique and very profitable scientific investigation that HST can perform in the post SM5 era. The proposed instrument is achievable and utilizes current technology that is steadily improving with time. The dedicated nature of the investigation greatly simplifies HST operations since only one instrument and one program is supported. This frees STScI personnel to prepare for JWST. The program is quite simple and is similar to programs previously carried out by HST. The output product of very deep 1 square degree fields provides unique resources to the entire scientific community and is a fitting final contribution for a telescope that has revolutionized our view of the universe. Since the time scale is short for action a proposed response is suggested in the next section.

Requested Action

To take advantage of this or even more innovative programs it is recommended that NASA immediately begin preparation of a Announcement of Opportunity for a SM5 instrument which will be issued as soon as possible to the community. If, and only if, programs and instruments are proposed that justify the additional cost of the mission and instrument, NASA should proceed to select the appropriate instrument. Unlike previous scientific instruments there should be no proprietary period associated with the observations. The AO could be directed along the lines discussed here or held open for other programs. Simplified post SM5 HST operation should be an important criteria for selection.

Figures

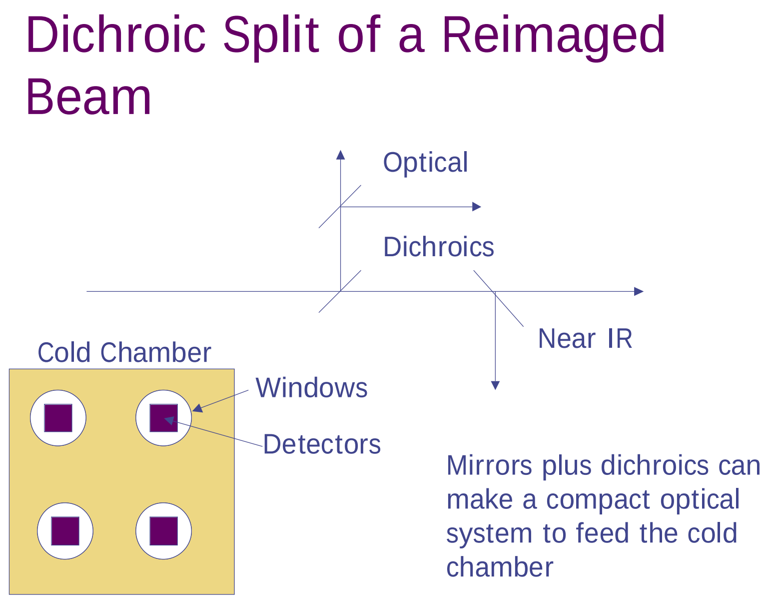

Figure 1. The dichroic placement is schematic to explicitly indicate the split of the optical and infrared bands. The split would occur in the final reimaged beam after correction for spherical aberration with pupil reimaging mirrors.

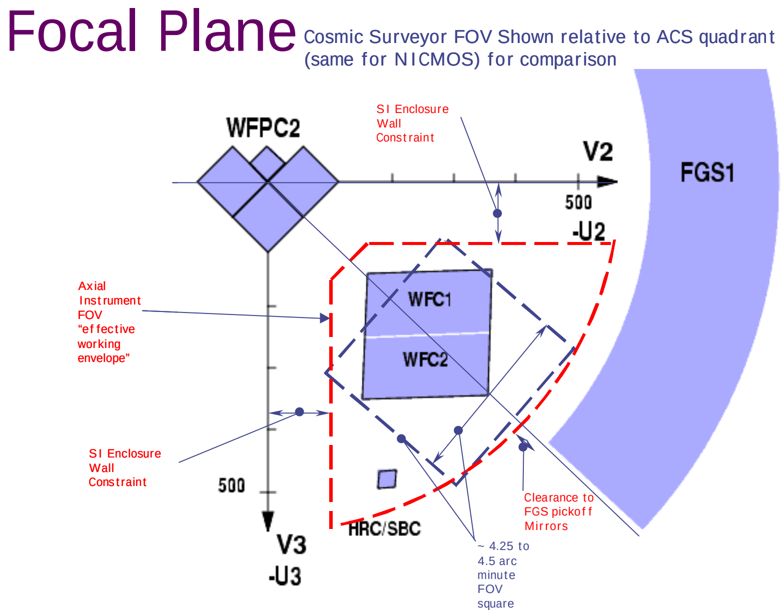

Figure 2. The maximal field of view is shown in this figure. The proposed field of view of 4x4 arc minutes is smaller than this maximal field. Preliminary optical designs indicate that 1/4 pixel or less geometric Point Spread Functions are achieved over the entire field.

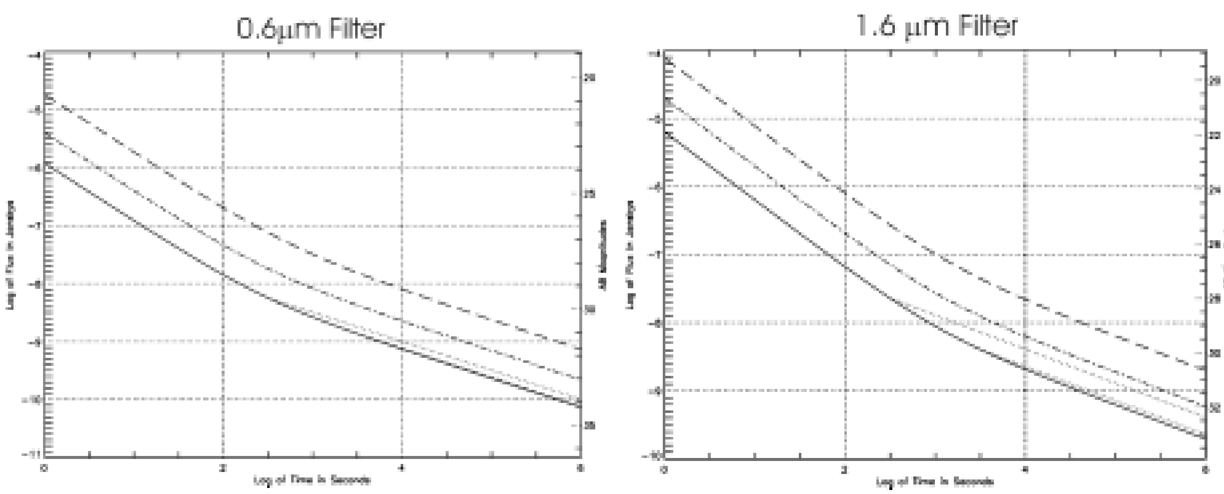

Figure 3. These figures show the flux in Janskys needed to produce signal to noise ratios of 1, 3 and 10 for an integration time indicated on the horizontal axis. This assumes a single integration. The dotted lines starting at 300 seconds and 3000 seconds show the fluxes needed for a signal to noise of one in a series of readouts of either 300 or 3000 seconds. The 300 seconds pertains to SNAP and the 3000 seconds pertains to CS. The 3000 second line for the 0.6μm filter blends with the plotted solid line. The difference between the two lines shows the deficit incurred by multiple short read out times. The smaller SNAP mirror will further degrade the sensitivity.

APPENDIX A: CS INSTRUMENT PARAMETERS

Number of Photometric Bands: 8
Bands Observed Simultaneously: 4
Wavelength Coverage: 0.25-1.8 μm
Optical Detector: 2 Rockwell Si on IR Mux (Hi-Vis)
Infrared Detector: 2 Rockwell Hawaii II GR with 1.8 μm cutoff
Detector and Cold Baffle Temperature: 130K

Photometric Characteristics

Table 1:

Filter	F28W	F36W	F46W	F59W	F76W	F97W	F124W	F159W
Center λ (μm)	0.28	0.36	0.46	0.59	0.76	0.97	1.24	1.59
Flux Limit* 10^{-9} Jy	0.43	0.44	0.37	0.38	0.65	0.60	0.63	1.1
AB Mag Limit*	32.3	32.3	32.5	32.5	31.9	32.0	31.9	31.3

*Flux and Mag limits refer to 1σ per pixel for one year of operation on a field. One year on a field will probably require two years of operation. At the end of two years of operation each of the two fields will have a full year of integration. The calculation assume 52 minutes of integration per HST orbit.